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Elements Which Have Contributed
To Dispersion In The
90/40mm Projectile (U)

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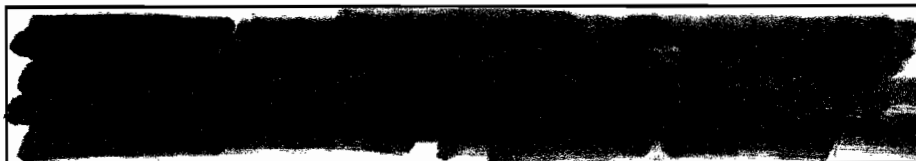


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William J. Gallagher

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REPORT NO. 1013

WJGallagher/jcw
Aberdeen Proving Ground, Md.
March 1957

ELEMENTS WHICH HAVE CONTRIBUTED TO DISPERSION
IN THE 90/40 MM PROJECTILE (U)

ABSTRACT

Through detailed analysis of Transonic Range firings, supplemented by open range firings by Development and Proof Services, an attempt has been made to determine the magnitudes of several causes which contribute to the dispersion of an arrow projectile. These causes of dispersion and their measured magnitudes are discussed in some detail. Values of the aerodynamic coefficients are also presented.

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TABLE OF SYMBOLS

B	Transverse Moment of Inertia	
K_{D_0}	Drag coefficient, zero yaw	
$K_{D_{\delta^2}}$	Yaw drag coefficient	
K_L	Lift force coefficient	
K_M	Righting moment coefficient	
K_N	Normal force coefficient	
K_1	Nutational arm of yawing motion	
K_2	Precessional arm of yawing motion	
K_3	Magnitude of displacement of epicyclic motion from center from boresight	
j_A	Deviation of projectile from boresight as a result of initial angular momentum	
j_T	Deviation of projectile from boresight as a result of initial transverse momentum	
Cp-Cg	Static stability margin	
Cp	Center of pressure	
Cg	Center of gravity	
RF	Reverse flow	
FF	Free Flight	
d	Diameter of projectile	inches
m	Mass of projectile	lbs
u	Velocity of projectile	ft/sec
$\dot{\delta}_0$	Initial yawing velocity	rad/sec
δ_{max}	First maximum yaw	degrees
$\xi_H + i\xi_V$	Complex representation of yaw	radians
ω	Natural frequency of yawing motion	deg/ft
ϕ_3	Orientation of vector K_3	
ϕ_3'	Rate of change of ϕ_3 with respect to range	rad/ft

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INTRODUCTION

In December, 1955, the Exterior Ballistics Laboratory was asked for assistance in examining causes of poor accuracy of the 90/40 Arrow shell. Ten rounds, which were allocated to us for this purpose, were fired on the Transonic Range in February of 1956. This paper is based principally on the results of these firings supplemented by firings conducted by the Development and Proof Services.

The T320 shell consists of a 40-mm diameter body, with conical wind-shield, and a 90-mm diameter tail. In January 1956, the T320-E37, a 12 caliber long, 11 lb. round was designated as the basic round. This round is non-spinning and fin-stabilized. It is driven by a four-piece scooped sabot. (Figure 1, Figure 8).

Initially the 90/40 projectile was a model of the 127/60-mm anti-aircraft projectile. Following some success with this type of a projectile at lower velocities (3900 fps), the program was accelerated when the 90/40's effectiveness as a kinetic energy armor piercing shot was discovered.

From limited terminal ballistics firings, the required terminal velocity for the carbide shot to defeat 5" of armor at 60° obliquity, has been placed at 4600 fps. In terms of the military requirement of 2000 yards and the aerodynamic drag of the 90/40, a muzzle velocity of 5200 fps was deemed necessary. This muzzle velocity requirement necessitated a new series of high velocity gun tubes such as the T208E3 and E4.

Performance of the shell, when fired at this higher velocity, was not satisfactory in that the accuracy of the round in terms of probable error was of the order of .6 mils at 1000 yards as opposed to the military requirement of .15 mils at 2000 yards.

Transonic Range tests were proposed to analyze the poor accuracy of the round and to examine causes of discrepancies between free flight and wind tunnel drag measurements as reflected in numerous firings prior to January 1956. Spark photography ranges with their high accuracy in position and attitude measurement are particularly suitable for these analyses⁽¹⁾.

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(Experience has shown that the overall accuracy of fit of the theory of motion of symmetric missiles to range data is .01 ft. in distance and .1 degree in angle.) Instrumentation within the range included cards at the beginning and end to measure spin, the 25 spark photography stations of the range, and microflash and mosaic type photographs within the range (Fig. 2). Extensive camera coverage outside of the range was made possible with the assistance of D&PS.

The following is a report on the Transonic Range firings. Section I is a presentation of the aerodynamic data and Section II is an analysis of dispersion.

I. AERODYNAMIC COEFFICIENTS

The desired terminal effect of the T320, 90/40 Arrow projectile, requires 4600 fps minimum striking velocity at 2000 yards. Therefore, even though the penetration and behind-the-plate effectiveness of this round have yet to be conclusively tested and evaluated, an accurate value of the drag coefficient which establishes the minimum acceptable muzzle velocity, was required. From the firings through the Transonic Range, the drag coefficient and other aerodynamic coefficients have been obtained⁽²⁾. These coefficients, the primary output of the range data reductions, were also important in the dispersion analysis which follows.

The test range of velocities was chosen to include the maximum velocity and the velocities at estimated fall-off to 1000 and 2000 yards.

Discussion

The aerodynamic coefficients are well determined with a few exceptions where either the yawing or swerving motion was not large enough. A tabulation of the Transonic Range determinations is given in Table I.

The static stability margin, i.e., the distance between the center of pressure in free flight and the center of gravity, is approximately 2 calibers over the range of velocities tested or about 17% of the projectile length, (Fig. 3).

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The dynamic stability compares favorably with similar shell⁽³⁾, such as the 127/60-mm. At Mach 4.38, the amplitude of the yawing motion damps to one-half of its initial value in approximately 500 feet of travel. The damping improves slightly with a decrease in Mach number. (Fig. 4)

The coefficients K_L (Figure 5) and K_M (Fig. 6) agree well with wind tunnel measurements. Wind tunnel measurements of the drag coefficients are plotted for comparison in Fig. 7. The zero-yaw drag coefficient, K_{D_0} , is computed from deceleration measurements of the projectile in free flight. These results show the value of K_{D_0} , extended to Mach 4.5, to be 0.114. This implies a fall-off of 290 fps in 1000 yards. Drag measurements made in the wind tunnel on 75% scale models give $K_{D_0} = .102$ at Mach 4.5. This results in a velocity drop of 260 fps in 1000 yards. Thus, in 2000 yards, the required range, there is a difference of 60 fps in fall-off indicating a corresponding penalty in the muzzle velocity.

Since this system was already quite demanding, it became necessary to determine whether the differences between wind tunnel and free flight values were real and if so, why they exist.

Drag Considerations

A comparison of photographs of the projectile before and after firing (Fig. 1, 8, 9, 10) shows that the leading edges of the fins of the round in flight have been damaged. Similar evidence shows that all of the rounds fired through the range were damaged at the leading edges of the fin. Consequently none of the rounds fired should be expected to yield the same drag coefficient as those tested in wind tunnels. Wind tunnel tests by Krieger have shown that the fin drag at supersonic speeds, may be as much as doubled (for the same sweep back) in going from sharp to blunt leading edges. The range data reductions, as described in the dispersion analysis, show that the damage to the fins may, in part, cause asymmetric lift forces which would influence the trajectory. Thus the drag values determined in these tests apply only to the tested rounds, or rounds with similar damage.

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Firings of various modifications of the T320 since July 1955, show photographic evidence of fin damage similar to that observed in Transonic Range firings.

This evidence indicates that for drag considerations alone, an improvement in fin strength or fin design is desirable. Such changes may also be helpful in improving dispersion as will be noted in the dispersion analysis.

The drag problem is an important one since the gun system now in use is approaching the allowable limit in pressure. Yet the present muzzle velocity is somewhat lower than required.

II. DISPERSION ANALYSIS

Knowledge of the aerodynamic characteristics of the T320E37 is rather complete from both wind tunnel results and the Transonic Range firings. These values, however, in themselves, do not explain the behavior of the round in flight.

A major portion of the investigation into the performance of the T320 shell was the determination of factors contributing to the poor accuracy of this round.

For a non-spinning round, such as the T320 with discarding sabot positioned over the center of gravity, the causes of deviation from boresight might be expected as follows:

1. Deviation resulting from gravity
2. Deviation resulting from initial angular momentum, j_A
3. Deviation resulting from initial transverse momentum imparted by muzzle blast, j_T
4. Deviation resulting from trim lift force, for asymmetric projectiles
5. Deviation resulting from asymmetric sabot discard.

The magnitudes of these contributors to deviation from boresight, at the Transonic Range target, located some 833 ft. from the gun muzzle, have been determined.

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The deviation of the actual strike on the target, from the boresight on the target is analysed in this report. Ideally, to determine the aiming point for dispersion accounting, a boresight would be desirable after the round is loaded. However, this could not be done. Instead, a boresight (Fig. 11) before loading and a back-sight after loading were used. The determination of this boresight differed from the conventional method in that it involved use of a muzzle - inserted telescope and an adjustable target light placed inside the Transonic Range.

Discussion of results

General

The yawing motions of projectiles as observed in the Transonic Range have been found to be amenable to vector representations of the following kinds. (2)(4)

The yawing motion of a symmetric missile can be represented as the sum of two rotating vectors (Fig. 12), K_1 and K_2 and is termed epicyclic motion. The yawing motion of an asymmetric projectile can be represented as the sum of three rotating vectors (Fig. 13), K_1 , K_2 , and K_3 , and is termed tricyclic yawing motion, and vector K_3 represents the magnitude of the displacement of the epicyclic motion from center (a measure of asymmetry). The orientation of vector K_3 is designated ϕ_3 . This third vector may have rotation greater than or equal to zero depending upon whether the projectile is spinning, i.e., $\phi_3 \geq 0$.

The motions of the ten rounds of T32OE37 were found capable of representation by the methods previously described within the following limitations. Four rounds exhibited epicyclic motions within an acceptable accuracy of overall fit to the theory of yawing and swerving motion of symmetric projectiles. Six rounds exhibited tricyclic motion. In addition to the effect of projectile asymmetries, these tricycle rounds also exhibited random spins upon exiting from the range. Thus ϕ_3 was not equal to zero for these rounds. For an exact representation of this type of motion, the rotation and phase of vector K_3 must be known. However, the spin at the entrance to the instrumented range was essentially zero and at the exit of the instrumented range, not greater than 1 deg/ft for any of the rounds. From these data and photographs

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over the first 153-foot interval between the muzzle and the range, the spin of the projectiles was observed to oscillate about zero before entering the range. Therefore, the spin was taken to be essentially zero over a considerable portion of the observed trajectory. Under this assumption, the motions of five of the six asymmetric rounds were found to be representable, within acceptable errors of fit, by a non-rolling, tricycle, i.e., $\phi_3^1 = 0$ for all rounds except one, which could not be reduced. The probable errors of the yaw and swerve fit to the theory of motion were of the order of .09 degrees in yaw and .007 feet in swerve. Parabolic deviations of ten times this magnitude were observed on the asymmetric rounds.

From the range data, the magnitudes of gravity drop, initial angular momentum, and trim lift contributions to dispersion can be inferred. In addition, under reasonable assumptions concerning the forces in the muzzle blast region, the deviation of the projectile resulting from the initial transverse momentum associated with the angular momentum may be computed. The contribution of asymmetric sabot discard to the deviation of the projectile from boresight is the most difficult to interpret.

Deviation Resulting from Gravity

For this analysis, the boresight was first corrected for gravity drop using actual time of flight data. This deviation is not, in the present work, a contributor to the dispersion but defines a gravity corrected boresight. The difference between the actual strike and the gravity corrected boresight is the subject of this analysis.

Deviation Resulting from Initial Angular Momentum (Aerodynamic Jump), j_A

One component of the deviation of a projectile from boresight is a result of its initial angular velocity.⁽⁵⁾ This displacement of the projectile from boresight is a function of the projectile's physical characteristics, free flight aerodynamics and initial free flight yawing velocity. In the analysis of the T320 projectile, the muzzle blast region was photographically observed to extend over the first ten feet of the trajectory. Further, several photographs indicated that sabot shock waves did not influence fin performance beyond 20 feet. On this basis, a point 20 feet from the muzzle was chosen as the origin of free flight for nine of the

rounds. Round 3878, however, exhibited a radial sabot discard as opposed to the more normal forward rotating discard (Fig. 9). Because the sabot segments for this round appeared to clear the fins earlier, a point 10 ft. from the muzzle was chosen as the origin of free flight. Yawing motions obtained in the range were extrapolated to these positions to determine the initial yaws and initial yawing velocities from which the deviations resulting from initial angular momentum (j_A) were computed.

From the results, the contribution of the initial angular momentum is seen to be a large one. Of the ten rounds analyzed here, five were found to have deviations from boresight, from this cause, of 1.5 mils to 2.4 mils.

The remaining rounds had deviations, j_A , of less than 1 mil but greater than 0.4 mil. No preferential plane of the jump was observed.

The jump of a non-spinning projectile resulting from initial angular momentum alone is a function of the free flight aerodynamics, the physical characteristics and the initial yawing velocity of the projectile as follows:

$$j_A = - \frac{K_L}{K_M} \frac{B}{md} \dot{\delta}_o \quad (1)$$

where

K_L = lift coefficient

K_M = righting moment coefficient

B = transverse moment of inertia - lb-in²

m = mass of the projectile - lbs

u = velocity of projectile - ft/sec

d = nominal diameter of projectile - in

$\dot{\delta}_o$ = initial yawing velocity - rad/sec

Equation (1) may be written as a function of the first maximum yaw which is easily measured:

$$j_A = \frac{-K_L B}{K_M md} \omega \delta_{max}$$

[REDACTED]

where ω = natural frequency of the yawing motion - deg/ft

δ_{\max} = first maximum yaw

Of the quantities defining the jump, j_A , all except the first maximum yaw (δ_{\max}) are known from either physical measurements, wind tunnel tests or Transonic Range firings and are constant for a given projectile and muzzle velocity. Hence, equation (2) describes the deviation expected per degree of first maximum yaw. For example, at Mach 4.38.

$$j_A = (.27 \text{ mils/deg}) \delta_{\max}$$

Deviation Resulting from Initial Transverse Momentum, j_T

A projectile subjected to asymmetric muzzle blast forces (either because of poor obturation, initial yaw, or yawing velocity or asymmetry of the projectile upon exiting from the muzzle) may be expected to deviate from the boresight line as a result of transverse momentum imparted by the muzzle blast, as well as from initial angular momentum.

In the Picatinny Arsenal Fin-Stabilized Committee meeting of June 1955, Kessler⁽⁶⁾ showed the cancellation effects of muzzle blast momentum. First, it was shown that the displacements resulting from transverse and angular momentum are 180 degrees out of phase. Then, for these out of phase displacements to cancel, it was shown that the centers of pressure in the reverse flow of the muzzle blast and in free flight should coincide.

An investigation into muzzle blast effects on the T320 during tests at the Transonic Range showed the following results.

In those cases where the aerodynamic jump, j_A , was greater than 1 mil, the displacement due to aerodynamic jump was 2.5 times as large as a transverse deviation, j_T , which was taken to lie in the plane of the initial yawing but in the opposite direction.

From the free flight tests, the $(C_p - C_g)_{FF}$ distance has been found to be 2 calibers (1 caliber = 40-mm); thus the $(C_p - C_g)_{RF}$ is 5 calibers.

Therefore, the center of pressure in reverse flow is at 1.2 calibers from the base of the projectile in agreement with estimates from the known aerodynamics of body and fins. The 3 caliber separation between free flight

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and reverse flow location of the center of pressure is typical of projectiles with large fins and slender bodies. There are, indeed, projectiles whose centers of pressure are nearly coincident. These projectiles have low lift noses and are not so sensitive to muzzle blast disturbances as the T320. These projectiles, however, are high drag shapes and cannot meet the requirements of terminal velocity placed upon the T320. Therefore, the T320 should be launched with good obturation and minimum initial yaw and yawing velocity in order to minimize the deviation caused by the muzzle blast mechanism on an otherwise symmetric projectile. Thus, unless design changes are made to this round, complete cancellation of j_A by j_T is not possible. Under this criterion, then, first maximum yaws of 1 degree or less must be maintained otherwise the deviation of the projectile due only to initial yawing and muzzle blast will be greater than 0.2 mils.

Deviation Resulting from Trim Lift Force for Asymmetric Projectiles

A description of the motion observed in the Transonic Range, as non-rolling and asymmetric (fixed tricycle) was found to be acceptable for five of the six asymmetric rounds in terms of data representation. That is, the asymmetry component of the swerving motion could be represented by a straight line and a tangent parabola. In two of these five rounds (No. 3876 and No. 3878) the spin was zero. In the other three cases, already described, the spin was never greater than 1 deg/ft upon existing from the range at 833 feet from the muzzle. In the zero spin rounds the contribution of asymmetry within the range can be realistically inferred from the magnitude of the K_3 vector. In the other three rounds there is evidence that the projectile oscillates about zero spin for the greater part of the observed trajectory and then takes on some spin acceleration. For these rounds the fixed tricycle representation is somewhat in error, but certain features of this type of representation are informative.

Under the assumption of zero spin, the contribution of asymmetry to the observed dispersion over the 833 feet of range was computed. These deviations in mils are as large as 1.27 mils at this distance and average .3 mils for this 10-round group. A non-rolling asymmetric missile trims in the plane of asymmetry at some angle of yaw. The resulting lift forces

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cause a parabolic departure of the missile from the boresight. Therefore, mil errors at different ranges will vary linearly with the distance.

In the case of spinning projectiles the asymmetric lift forces are averaged over the trajectory. The mil error is therefore small and constant with range.

The K_3 vector may be interpreted as a measure of asymmetry. An equivalent total tail misalignment of about 0.3 degree would have been required to produce the observed parabolic deviations. Fin damage sustained during firing as illustrated during the discussion of drag is suspected of being a contributor to total projectile asymmetries. This type of damage compounds inherent asymmetries as a result of manufacturing tolerances from which ordinarily an effective tail asymmetry of 0.1 degree might be expected.

Summation of Deviations from Boresight

A summation of these causes of deviation from boresight results in a non-closure of the dispersion diagram (Fig. 15). For those rounds where the phase relationships were determined, the non-closure was found to be as large as .5 mils. This difference may include the discrepancy between the boresight before and after loading and may also reflect the contribution of asymmetric sabot discard.

Deviation Resulting from Asymmetric Sabot Discard

Sabot discard may be regarded as unsatisfactory if it contributes to the deviation of the projectile from boresight. In general, asymmetric sabot discard would be suspect since the interchange of momentum between sabot and projectile might be substantial. However, determination of the symmetry or asymmetry of separation is difficult since the discard occurs in a segment of the trajectory which is obscured by muzzle gases and is not easily penetrated. Therefore, obtaining quantitative data is difficult.

In firings of the T320 during 1956 for Picatinny Arsenal, good attempts were made to obtain information on sabot separation. Radiographs were taken at the muzzle and at five feet from the muzzle on several rounds. Powerful backlighting was used in an attempt to see through the muzzle gases. High

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speed camera photographs were taken at ten feet from the muzzle and beyond; and yaw cards were placed at 80 feet from the muzzle and beyond.

The streak photographs at an early point in the trajectory are the most informative. These photographs show, in the vertical (Fig. 14) plane, the top and bottom sabot segments. The distance from the projectile axis to the center of gravity of the top and bottom segments can be measured. These observations show only the relationship of center of sabot symmetry, in one plane, of the segments measured to the projectile axis at the distance photographed.

Measurements, expressed in mils, of the distance between the midpoint of the two segments observed and the projectile axis have been made on 47 rounds. This displacement between sabot center of gravity and projectile axis at the position photographed was found to be $1.2 \text{ mils} \pm .9 \text{ mils}$ standard deviation. The individual measurements are tabulated in Table II.

Any interpretation of these measurements depends upon the manner in which the sabot separates. This process may be postulated to occur in several ways. It, of course, becomes a matter of physical observation as to which description is valid.

In the simplest interpretation, the assumption may be made that only sabot-projectile interaction takes place in a symmetric muzzle blast regime. In this case, coincidence of the center of gravity of the sabot segments with the axis of the projectile would be an indication of symmetric sabot discard.

The measurements, interpreted in this way, do not indicate that separation is symmetric. Further, if the assumption is added that momentum is exchanged between sabot and projectile in proportion to the ratio of their masses, a magnitude of contribution by the sabot to deviation may be ascribed to the measurements. Under this assumption about .45 mils deviation would have been expected as a result of the sabot discard.

CONCLUSIONS

The preceding analysis, exclusive of the sabot discard, has described several contributors to dispersion of the T320E37 projectile on the evidence of ten rounds fired through the Transonic Range. A great number of firings

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of this projectile with modifications to the sabot or the round have been made by Development and Proof Services at Aberdeen Proving Ground.⁽⁷⁾ The data collected on these rounds give firm support to the Transonic Range observations. The average probable error of these firings between January and September 1956 show fairly large dispersions, of the order of 0.6 mils. First maximum yaws ranged from 1 to 12 degrees with an average of roughly 4 degrees.

Analysis of sabot discard shows that there is no evidence of symmetric separation as previously described. Also, graphs of individual projectile strikes (plotted in mils) about a gravity corrected boresight at 50 yards and 1000 yards do not superimpose. This non-superposition indicates a range dependent deviation.

The analysis of Transonic Range firings has shown the major individual causes of dispersion of the ten rounds to be:

	<u>Total mils</u>
1. Deviation resulting from muzzle blast effects:	.7
this is composed of two effects opposite in direction:	
a. due to initial angular momentum	.9
b. due to initial transverse momentum	.2
2. Deviation resulting from trim lift (at 833' and zero spin)	.3
3. Deviation resulting from asymmetric sabot discard.	unknown

These effects may, of course, be subtractive or additive.

As mentioned, projectile asymmetries caused additional average displacement of the projectile, for the group tested, of .3 mils at 833 feet from the muzzle. If extrapolated to 1000 yards, on the assumption that the projectile does not spin, these asymmetries will cause a departure from boresight (gravity corrected) of the order of 1 mil. It is interesting to note that careful examination of 38 firings of the T32OE37 by Development and Proof Services of Aberdeen also show the presence of asymmetry affecting the flight path of the projectile. When the gravity corrected patterns of strikes, expressed in mils, on 50-yard and 1000 - yard targets are super-

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imposed, they fail to agree. (Fig. 16) The average differences for each round between the strikes on the two targets is about .8 mil (Table III). This is in excellent agreement with the effect of asymmetries observed in the Transonic Range on a ten-round sample. In addition, tabulation of some 180 rounds has shown that 10% of the rounds missed a 1000-yard target. This may be a consequence of zero spin.

Figure 17 shows the analysis of impact on a target card at 50 yards from the muzzle. At this range deviations resulting from trim lift forces are small. The slope of a line through the origin is about 0.2 mils per degree of first maximum yaw. This analysis of D&PS firings shows excellent confirmation of predictions (based on Transonic Range firings) of projectile deflection resulting from the interaction of initial angular and transverse momenta in the muzzle blast. From the Transonic Range analysis of muzzle blast, 0.2 mil deviation of the projectile per degree of first maximum yaw was established. Therefore, first maximum yaw of one degree or less must be maintained in order to approach the desired accuracy.

Thus the present analysis shows that the poor accuracy of the T320 is due to various causes, the elimination of which requires systematic investigations designed to isolate, if possible, one variable at a time.

A projectile's trajectory is determined largely by launching conditions, e.g., muzzle blast effects or sabot discard. Therefore, launching conditions should be studied carefully. The region of projectile travel inside the gun tube should be investigated in order to determine whether tolerances between sabot and gun tube and between projectile fins and gun tube are resulting in undesirable large exit yaw or yawing velocity. Rounds with interference fit on fins and sabots should be tested in order to determine the influence of bore clearances. This test should logically be performed first. Further investigations into the muzzle blast region and sabot separation, using this same type of projectile, should be undertaken following these tests. Otherwise it would be very difficult to separate individual contributing causes to poor launching.

The problem of downrange dispersion resulting from asymmetry of the projectile, primarily of the fins, is in addition to the problems of launching just discussed. Projectile asymmetries either from the manu-

facturing process, or the firing of the projectile, or both, cause unbalanced lift forces to act on the projectile. The result is that for a non-spinning round a parabolic deviation from boresight occurs and that for a properly spinning round the effects of the lift force are averaged over the trajectory.

The selection of a proper spin is dependent upon the natural frequency of the yawing motion (which, for the T320E37, is about 2.1 deg/ft) and, as an upper bound, by the region of Magnus instability (which for similar rounds is about 10 deg/ft⁽³⁾). Therefore, a spin in the range from 3 to 10 deg/ft should be satisfactory. The choice of spin for the T320, however, is affected by its HE companion the T340. The T340 has exhibited weakened yaw damping at spin levels of the order of 6-1/2 deg/ft. Thus, a choice of spin between 3 and 6 deg/ft should be satisfactory. If a rifled tube is used for inducing such spins, a twist of rifling of one turn in 240 calibers of travel will produce such a spin. Spin reduces initial jump resulting from asymmetry and improves dispersion resulting from projectile asymmetries acting down range. The asymmetry of this round should be, in any case, maintained at a minimum level in order to improve both launching and subsequent flight. Maintenance of closer manufacturing tolerances, re-design of the fin leading edge, or strengthening of metal parts to prevent erosion are possible means of combating asymmetry.

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ADDENDUM

Additional experimental firings by Development and Proof Services for Picatinny Arsenal since 18 October 1956 have yielded important results. Firings of the kind recommended in the conclusions of this report were performed in November and December of 1956. The projectiles and sabots for these tests were modified so that both fin diameters and sabot diameters were approximately .016 inches larger than the bore diameter of the gun tube. In addition, the projectiles were carefully selected for body alignment. The results were most encouraging. First maximum yaws in these tests were generally less than 2 degrees and for many rounds less than 1 degree. The probable errors at 1000 yards for groups of these interference fit projectiles have been of the order of .25 mils horizontally and vertically. This is a substantial improvement over previous firings of loose tolerance projectiles. Having thus isolated one of the variables discussed in the body of this report, further tests with these projectiles (now designated T32OE60) to determine the influence of trim lift forces should be performed. Production rounds of the E60 should be tested to long ranges with adequate instrumentation to detect asymmetric flight. The results of such tests will indicate whether spin is required to maintain accuracy to long ranges.

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6. E. L. Kessler, The "Jump" Equation and Some of Its Implications for the Design of Slowly Spinning Fin Stabilized Projectiles Proceedings of the Fin Stabilized Ammunition Committee, 15 June 1955.
7. Development and Proof Services TAL-1475 Project Reports, Aberdeen Proving Ground, Md., January September 1956.

SUPPLEMENTARY

1. Kelley, McShane, Reno Exterior Ballistics University of Denver Press.
2. L. C. MacAllister, Comments on the Preliminary Reduction of Symmetric and Asymmetric Yawing Motion BRLM Report 781.
3. K. Betz, A Tricycle Swerve Reduction, BRLM Report 847.

TABLE I

AERODYNAMIC COEFFICIENTS

AND

THE STANDARD DEVIATION IN THEIR DETERMINATION

Type of Reduction	Round No.	Mach No.	K_D	K_L	K_M	λ_{1-2} Avg. 1/Ft	K_N	K_{D_0}	$K_{D_0^2}$	δ^2 deg.
Tricycle	3871	4.36	.124 .46%	3.08* 11.6%	-7.07 .33%	1.12 8.5%	3.20	.1145	.00133	9.35
	Stnd Dev.									
Epicycle	3872	4.37	.117 .60%		-7.38	1.55** 13.7%				.62
Tricycle	3873	4.38	.130 .78%	3.26 10.1%	-7.09 .58%	1.27 11.7%	3.39			12.55
Tricycle	3874	4.40	.120 .59%	3.45* 18.8%	-6.91 .56%	1.14 13.7%	3.57			3.25
Tricycle	3875	4.36	.117 .45%	3.15* 76.81%	-7.03 1.54%	**	3.26			.96
Tricycle	3876	4.21	.137 .38%	3.73 6.59%	-7.13 .14%	1.05 4.4%	3.86	.1160	.00133	13.99
Epicycle	3877	4.30	.118 .24%	3.71* 34.1%	-7.46 .74%	1.44** 12.9%	3.83			1.05
Tricycle	3878	4.29	.117 .61%	3.15* 17.0%	-6.85 .37%	1.11 10.8%	3.26			4.29
Epicycle	3879	3.93	.132 .48%	3.67 10.9%	-8.29 .29%	1.29 5.9%	3.81	.1180	.00133	11.26
Epicycle	3880	3.94	.136 .47%	3.73 11.4%	-7.96 .21%	1.38 3.8%	3.87			13.04

* Mag. of lift swerve < required for determination of lift coefficient.

** Mag. of yaw < required for determination of damping rates.

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TABLE II
DISTANCE BETWEEN SABOT'S CENTER OF GRAVITY
AND
PROJECTILE CENTER OF GRAVITY

<u>Date Fired and Location</u>	<u>Round No.</u>	<u>Separation Distance Mils</u>	<u>Date Fired and Location</u>	<u>Round No.</u>	<u>Separation Distance Mils</u>
19 Jan	6	- .32		3871	+ .32
D&PS	7	+2.12	BRL	3872	+ .37
	8	+ .81		3873	+1.63
21 Jan	11	- .95		3874	+ .37
D&PS	13	+1.27		3875	- .32
	14	- .64		3876	-3.26
	15	+ .32		3877	+ .74
23 Jan	16	- .32		3878	- .68
D&PS	17	+ .63		3879	+ .68
	18	+3.81		3880	+ .37
	19	+1.27			
	20	+ .64	6 April	8	-1.30
8 Feb	23	- .26	D&PS	9	-1.23
D&PS	24	-1.03		10	+0.32
	25	-2.57		11	+0.32
9 Feb	28	-3.33		12	-0.32
D&PS	29	+2.31	11 April	13	+ .41
10 Feb	31	-3.08	D&PS	14	+ .41
D&PS	32	+1.80		15	+ .45
	34	+2.31	12 April	17	+ .18
	35	+2.31	D&PS	18	-1.62
13 Feb	36	+1.28		20	- .59
D&PS	37	- .26			
	38	+1.54			
	39	-1.03			

NOTE: These are measurements of streak camera photographs in the interval 10 feet to 20 feet from the muzzle.

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TABLE III

DIFFERENCE, IN MILS, BETWEEN IMPACT POINTS AT 50 YARDS
AND
1000 YARDS WITH RESPECT TO BORESIGHT

Firings by D&PS in
T320E37 Projectile

<u>Date</u>	<u>Round No.</u>	<u>Difference in mils</u>	<u>Date</u>	<u>Round No.</u>	<u>Difference in mils</u>
13, 14,	1	2.3	13 Feb	1	.6
15, 16,	2	.3		2	.9
18, 19,	3	.45		3	1.5*
Jan	4	.75		4	.95
	5	.25		5	.6
	6	.3			
	7	.6	12 Apr	1	.4
	8	.3		2	.9
	9	2.0		3	.6
	10	1.0		4	.8
21 Jan	1	1.05	12 Apr	1	.3
	2	.25		2	.65
	3	----		3	.35
	4	.40		4	.8
	5	.2		5	.3
				6	.35
9 Feb	1	1.7		7	.8
	2	.4		8	.9
	3	.65		9	1.4
	4	1.4		10	2.0*
	5	1.1			

* These rounds missed the 1000 yard target after having hit the 50 yard yaw card.

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90/40 mm PROJECTILE T320E37 IN SABOT

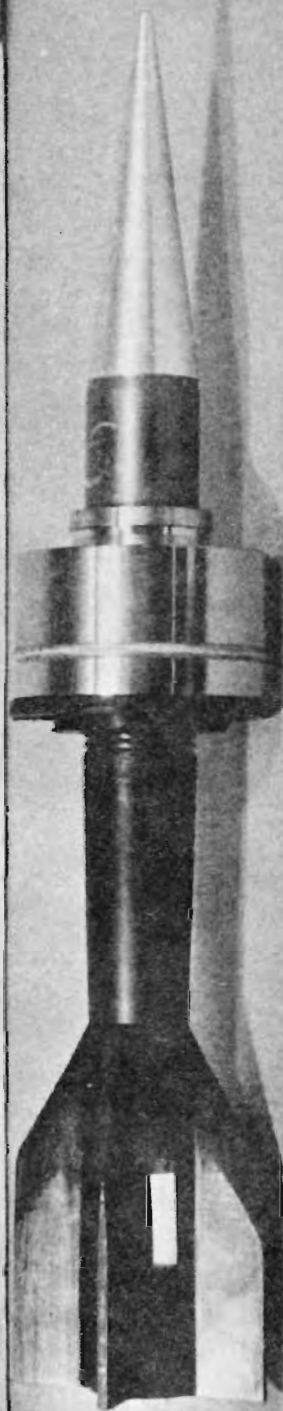
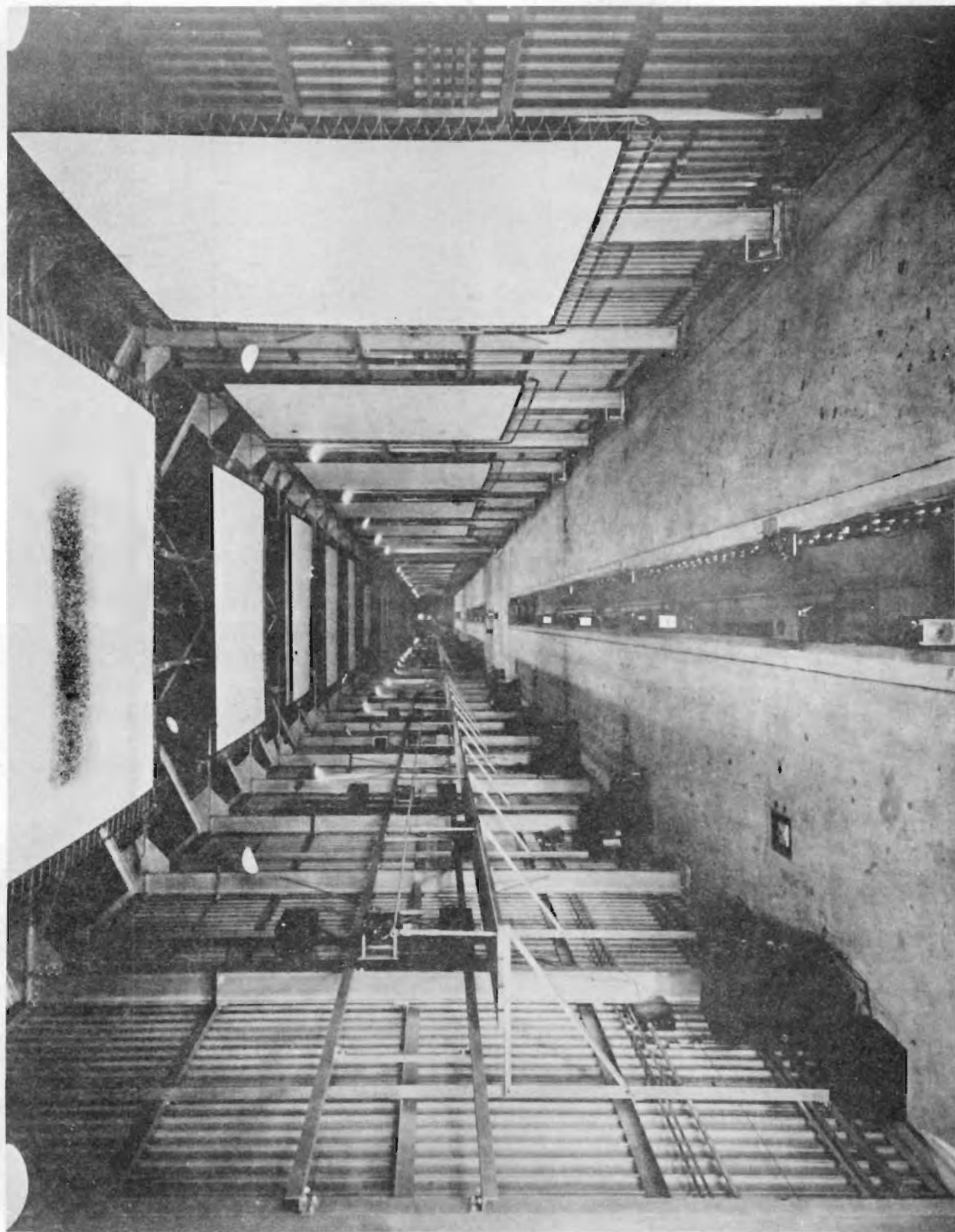


FIG. 1

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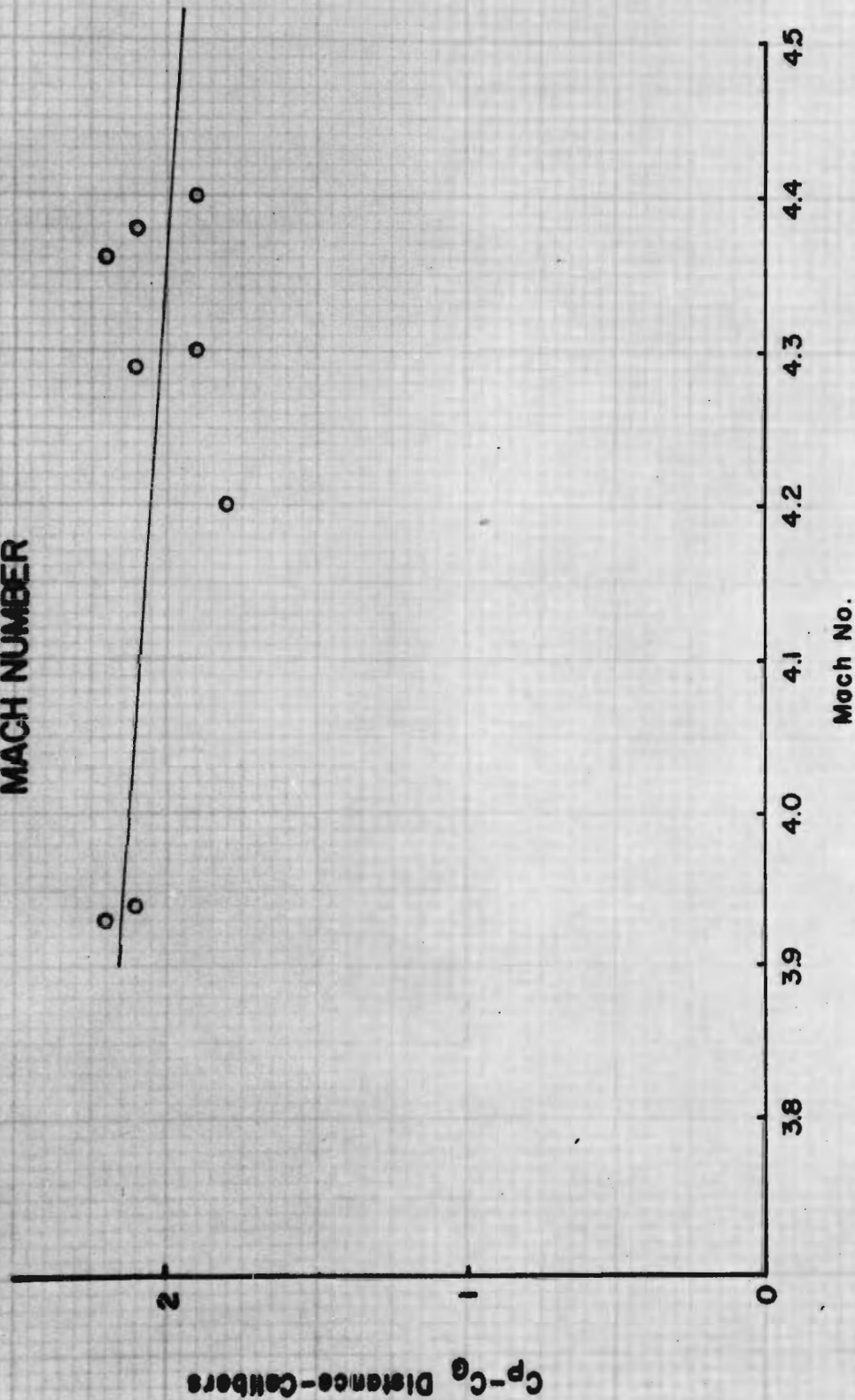
TRANSONIC RANGE

FIG. 2

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ABERDEEN PROVING GROUND, MD.
STEAP-TL

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STATIC STABILITY MARGIN
vs
MACH NUMBER



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FIG. 3

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DAMPING RATES
vs
MACH NUMBER

Average of λ_1 & $\lambda_2 - \frac{ft}{-}$

10⁻³

200

150

100

.50

0

3.8

3.9

4.0

4.1

4.2

4.3

4.4

4.5

Mach No.

FIG. 4

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LIFT COEFFICIENT
vs
MACH NUMBER

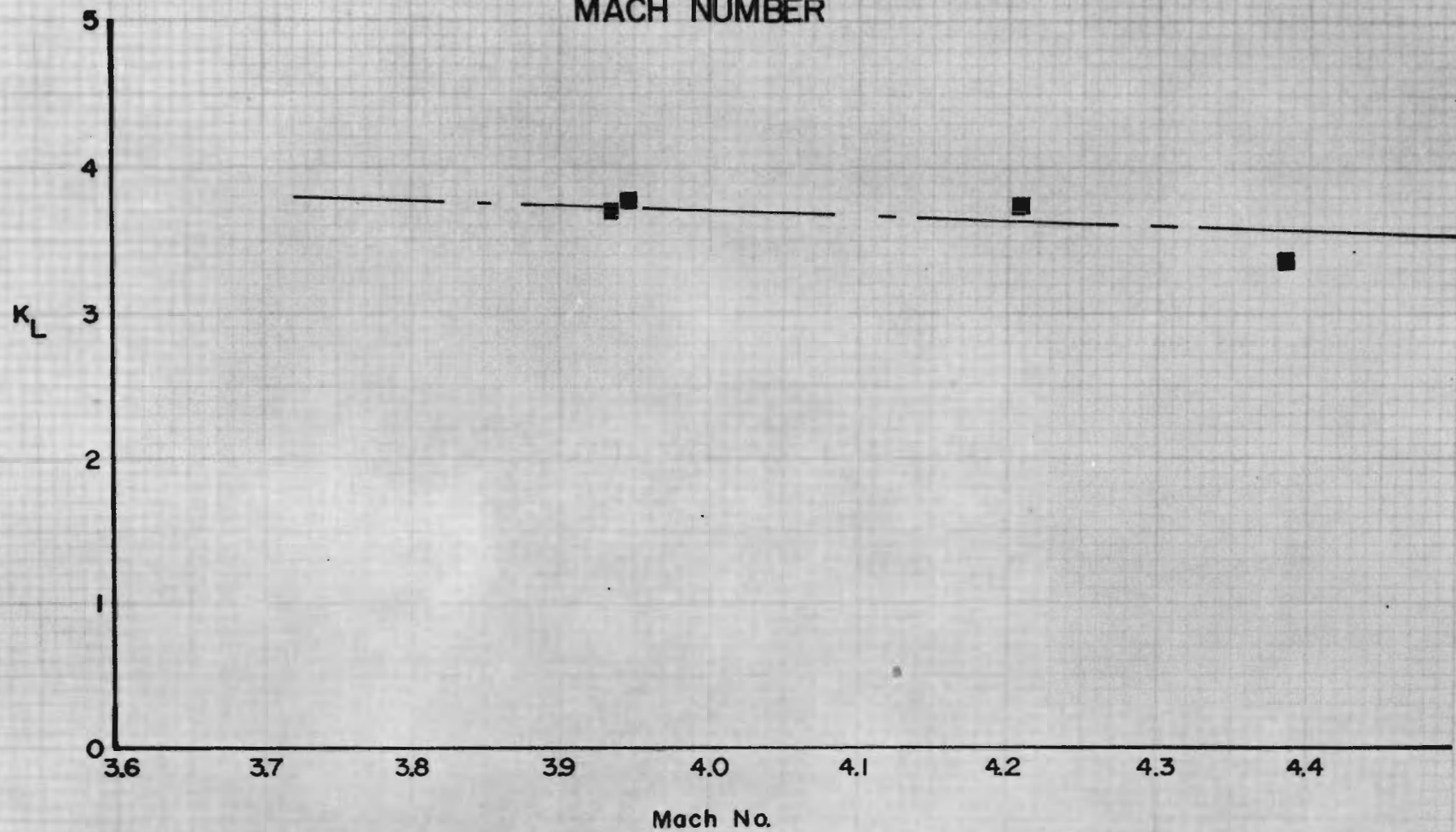


FIG. 5

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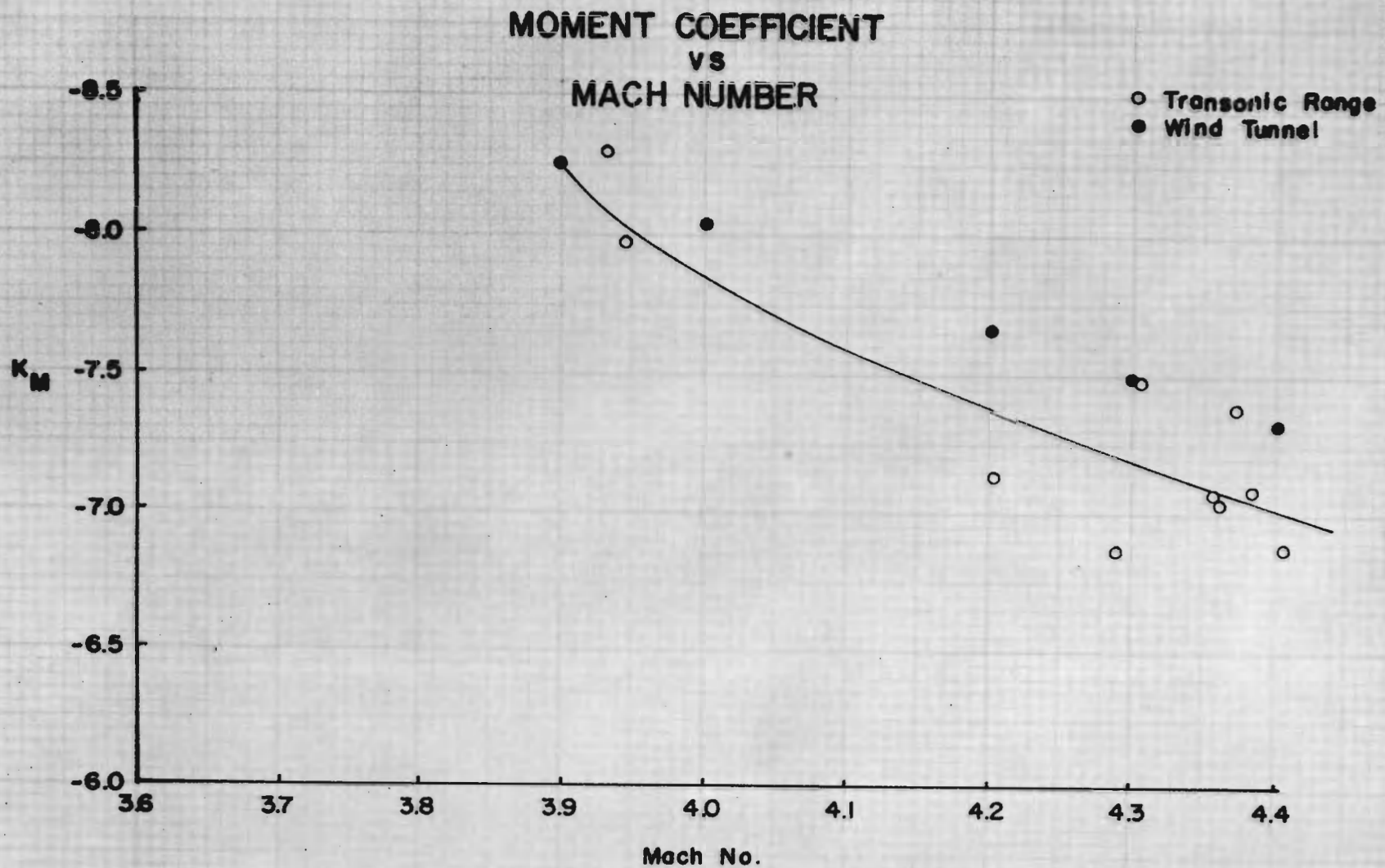


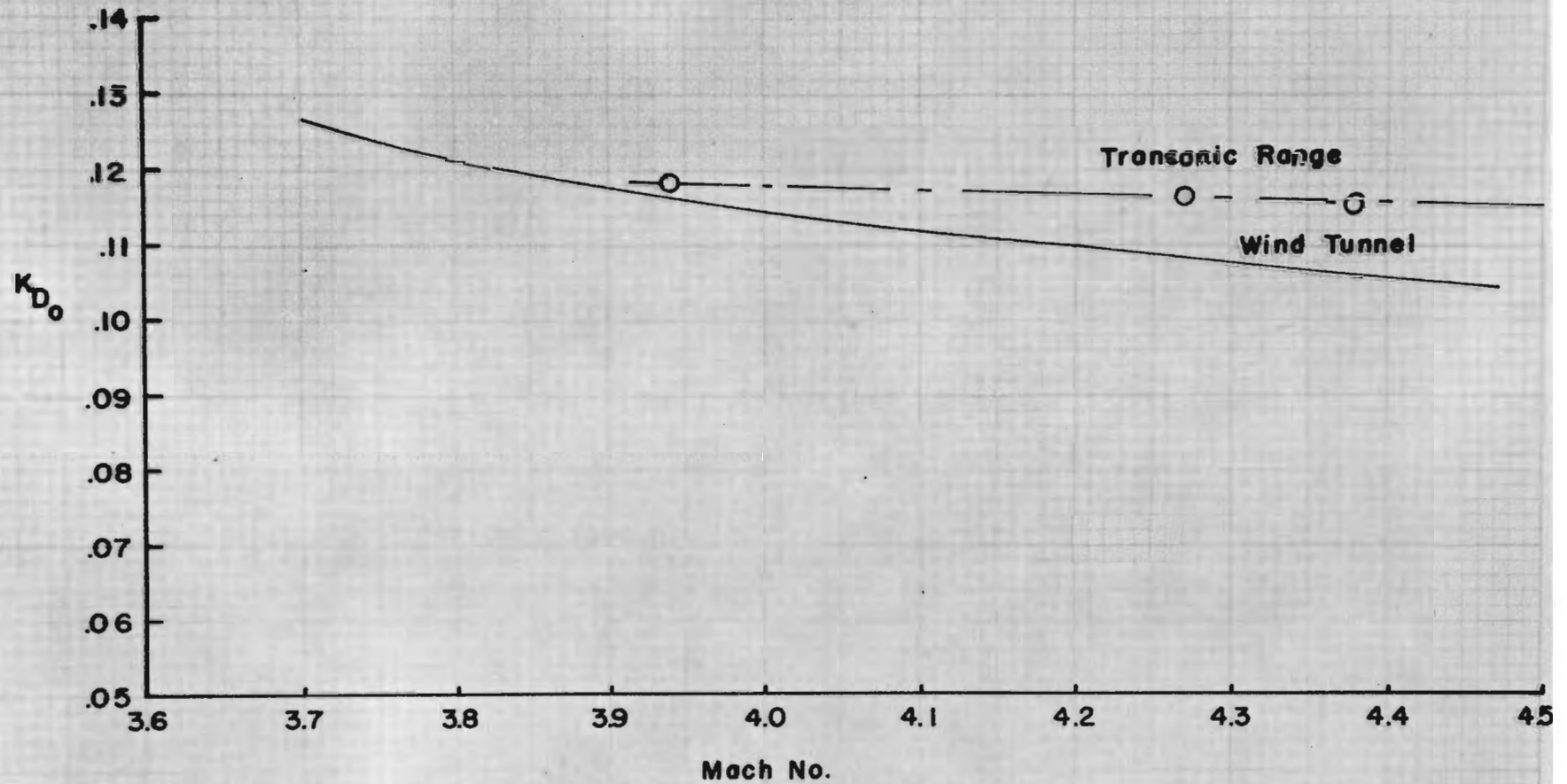
FIG. 6

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ZERO-YAW DRAG COEFFICIENT VS MACH NUMBER



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FIG. 7

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90/40 mm T320E37 WITH SABOT SEGMENTS

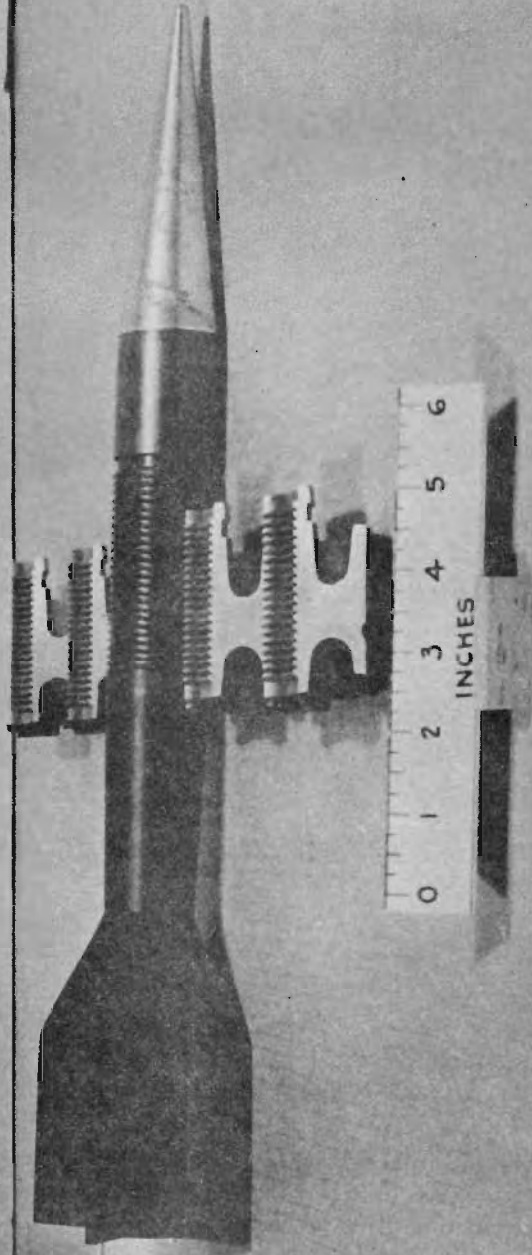


FIG.8

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90/40 IN FLIGHT 12 FEET FROM MUZZLE T320E37 M~4.2

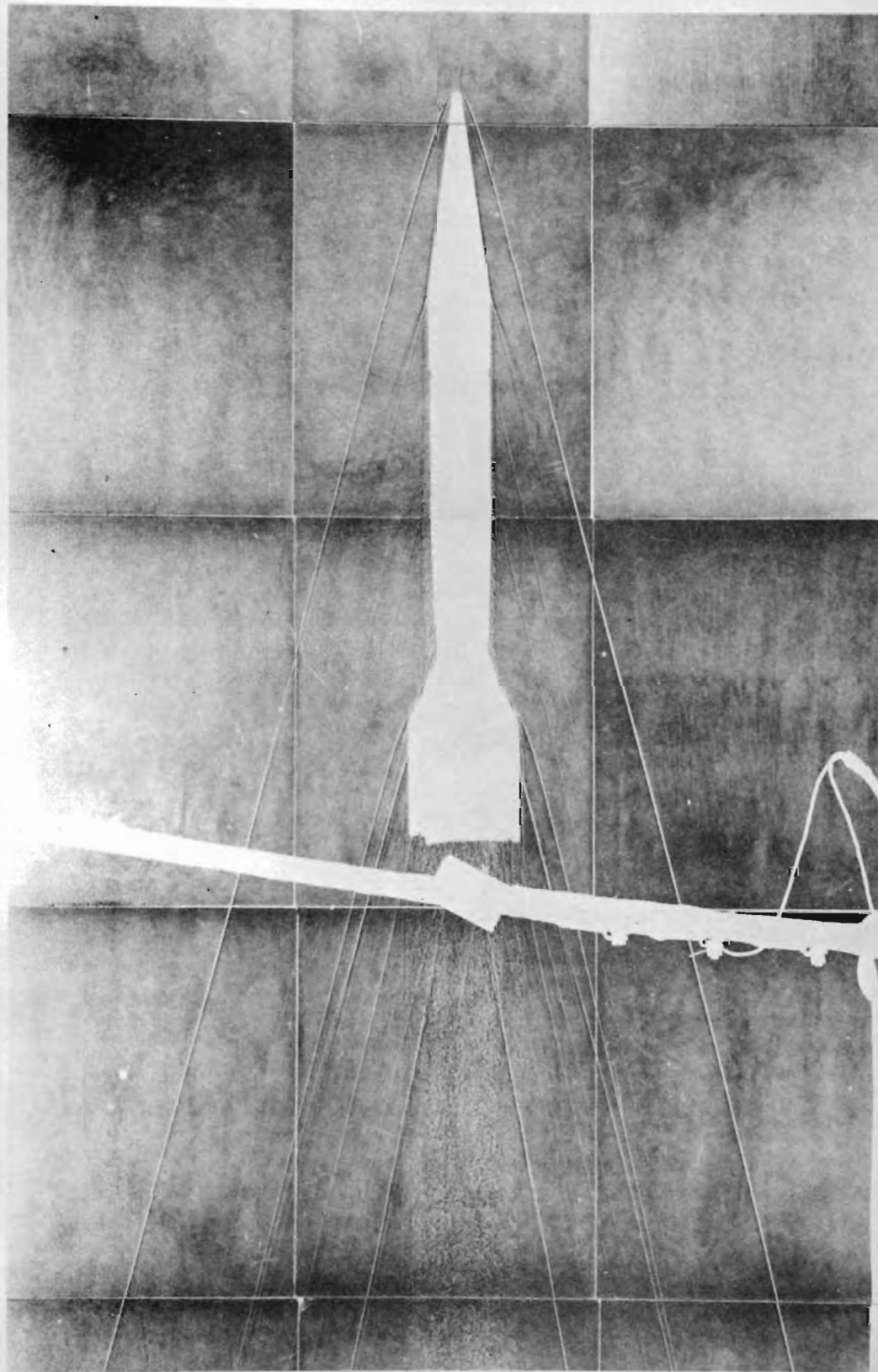


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FIG. 9

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SHADOWGRAPH OF 90/40 T320E37 IN FLIGHT 300 FT. FROM MUZZLE M~4.35



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FIG. 10

BORESIGHTING TELESCOPE AND MUZZLE MOTION INDICATOR T208E3 GUN TUBE

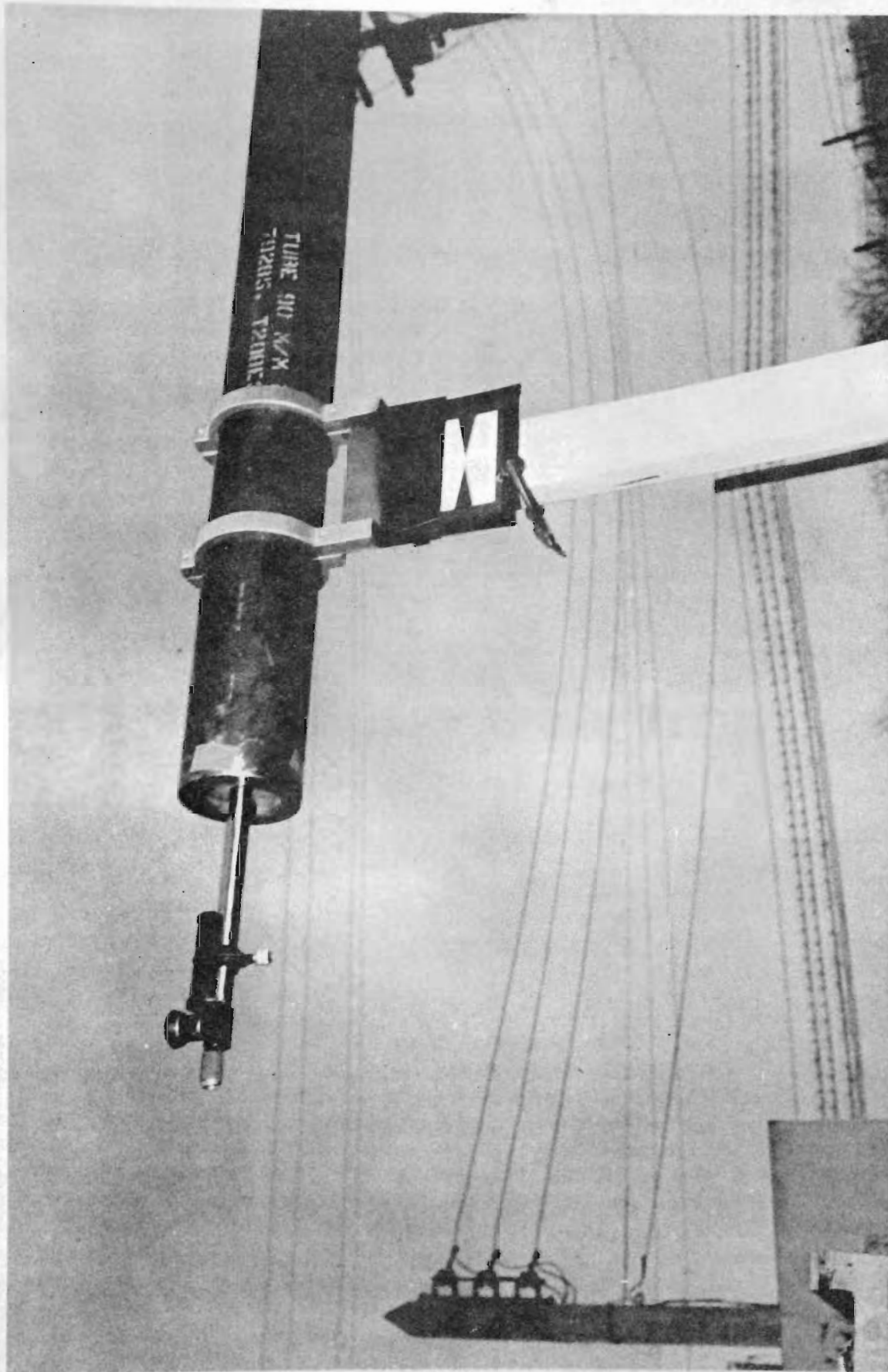


FIG. II

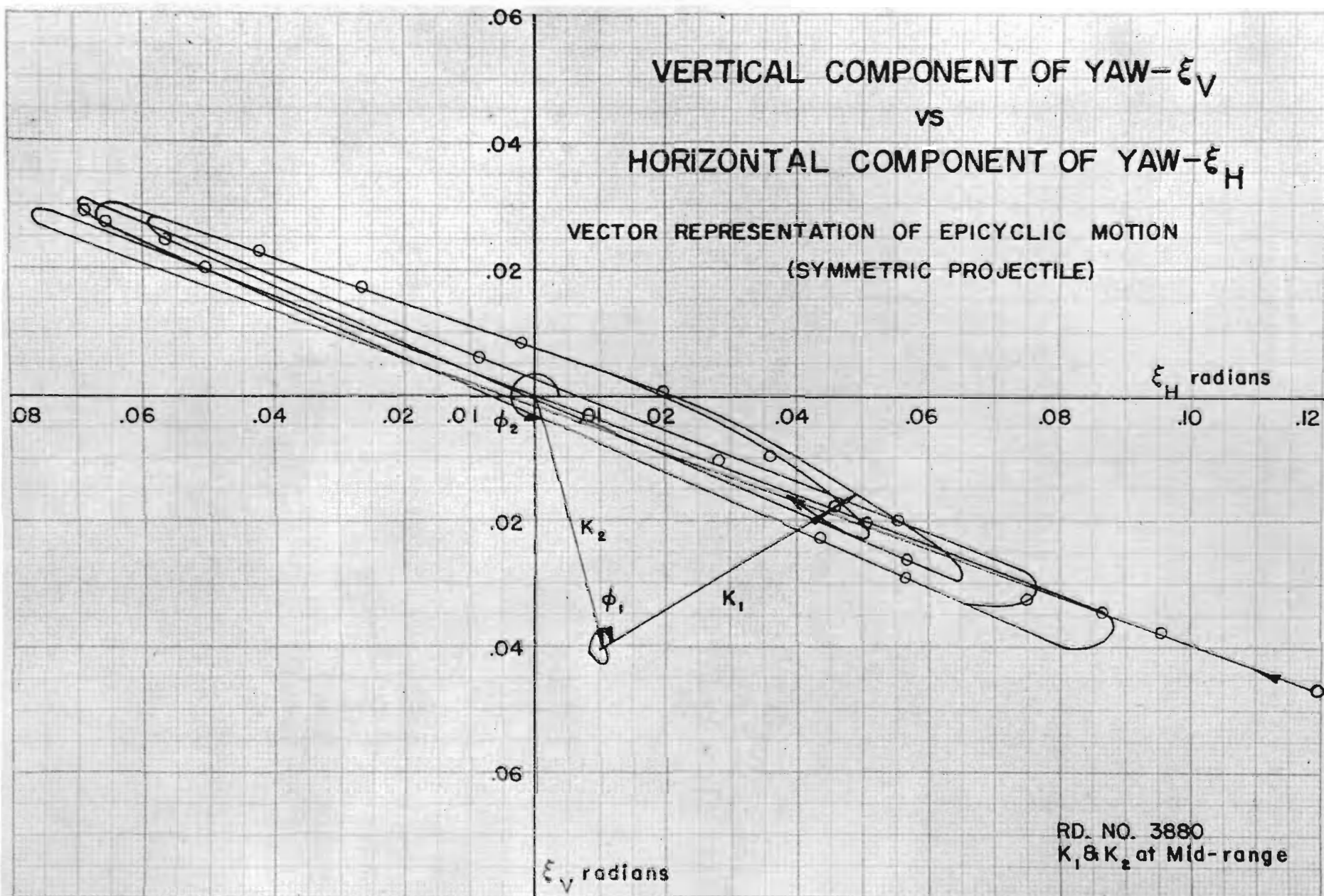
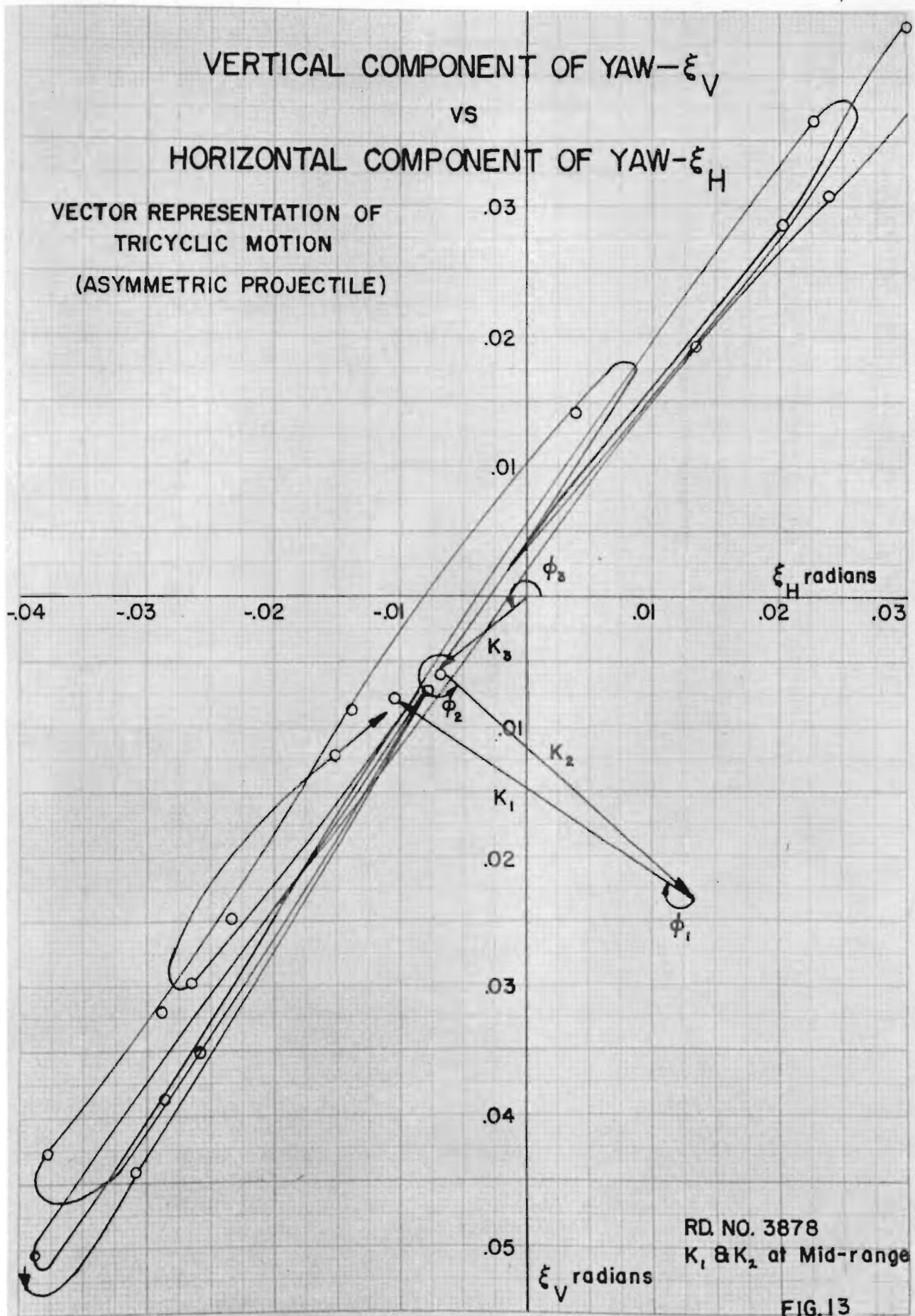
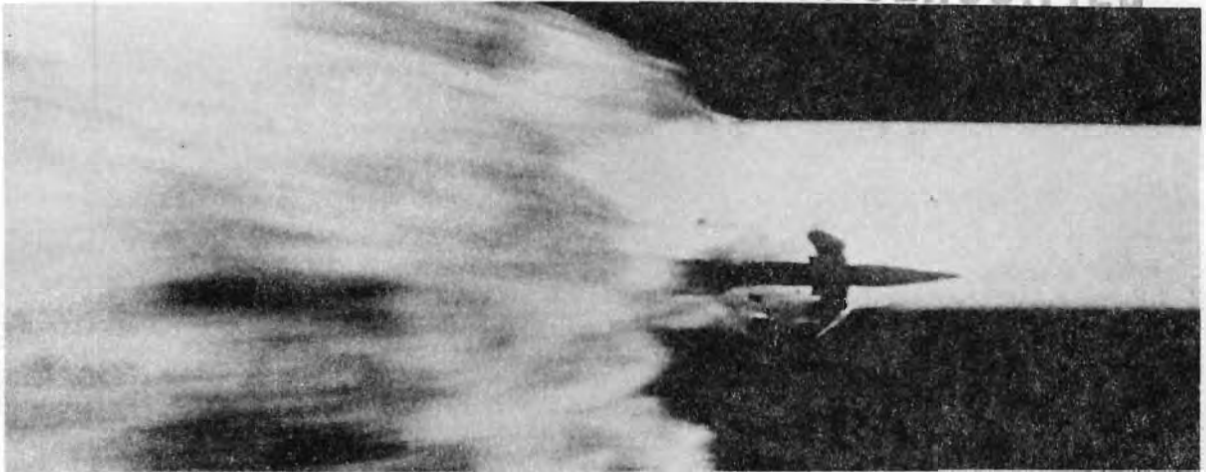


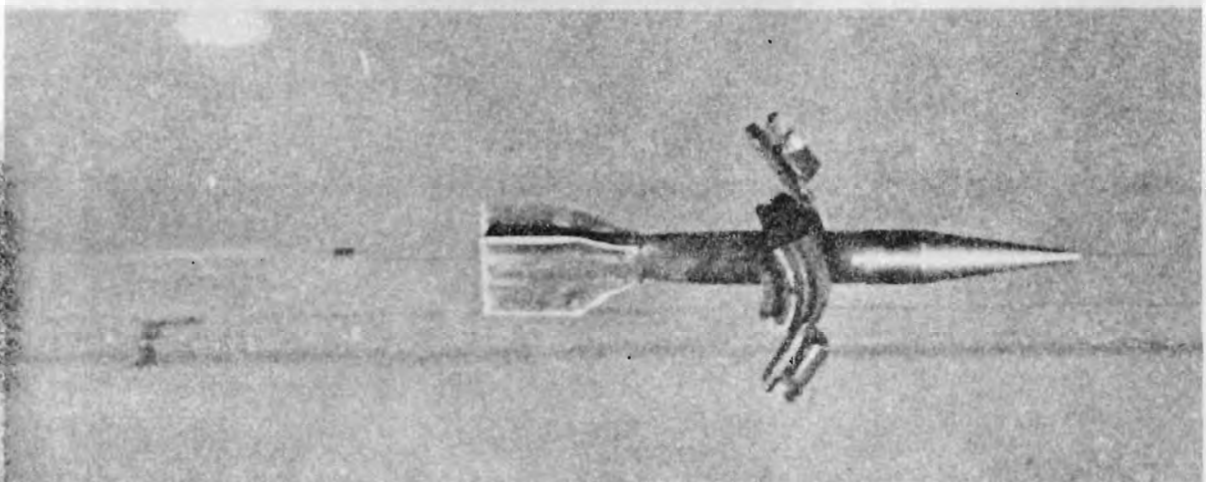
FIG. 12



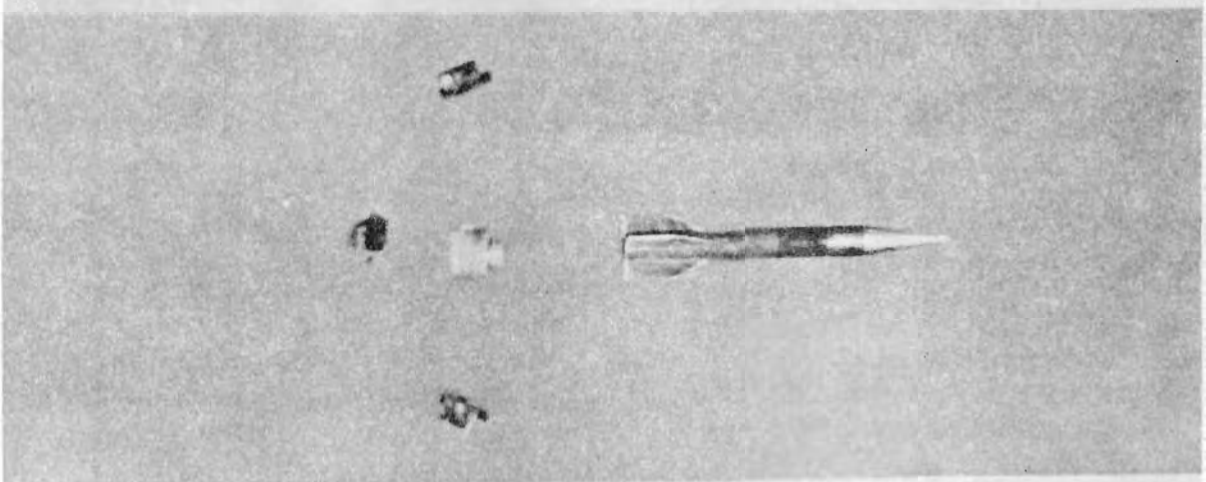
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5 FT. FROM MUZZLE



12 FT. FROM MUZZLE

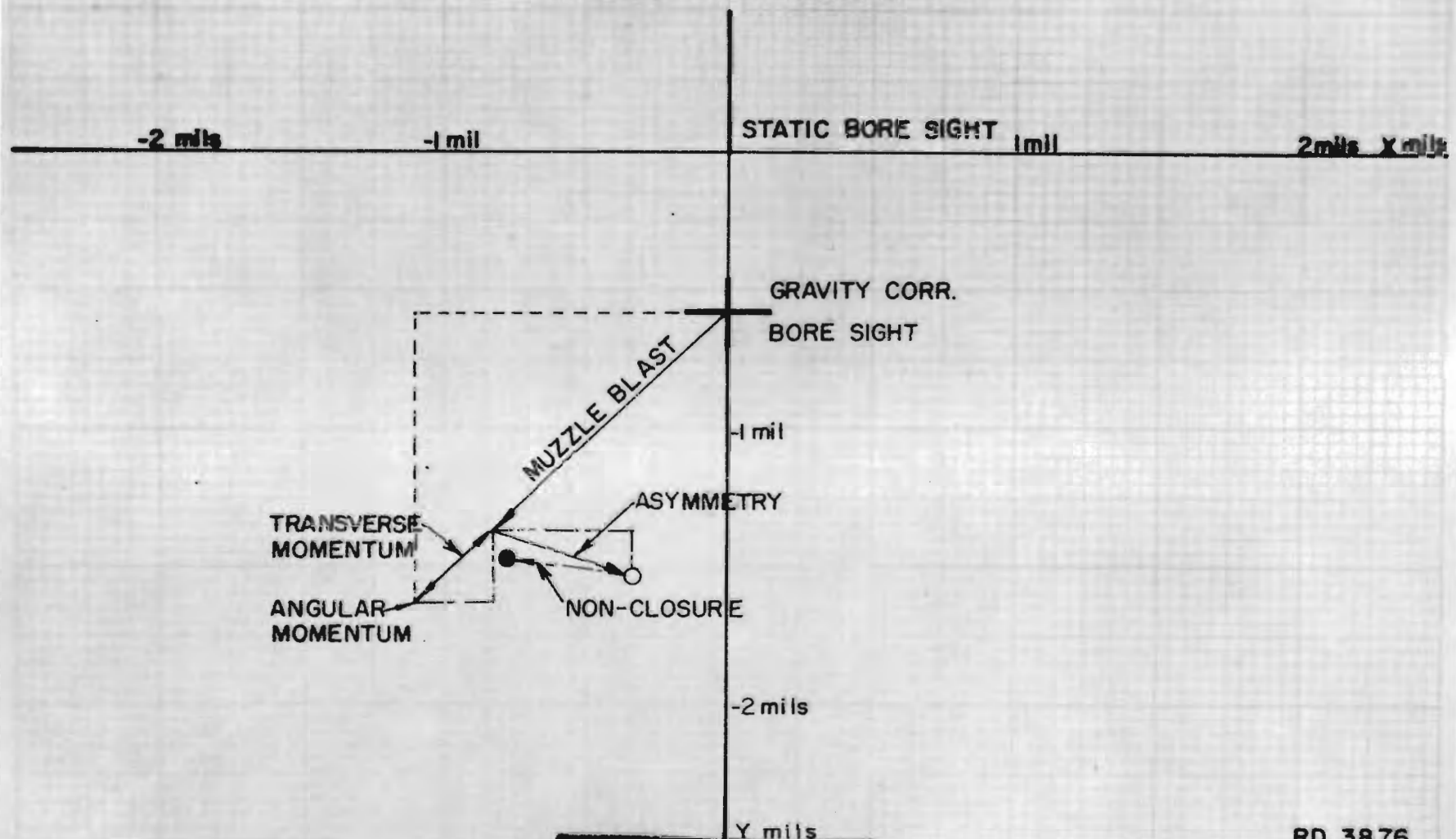


40 FT. FROM MUZZLE

90/40 IN FLIGHT

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**SINGLE ROUND
DISPERSION DIAGRAM
AT 833' FROM MUZZLE**



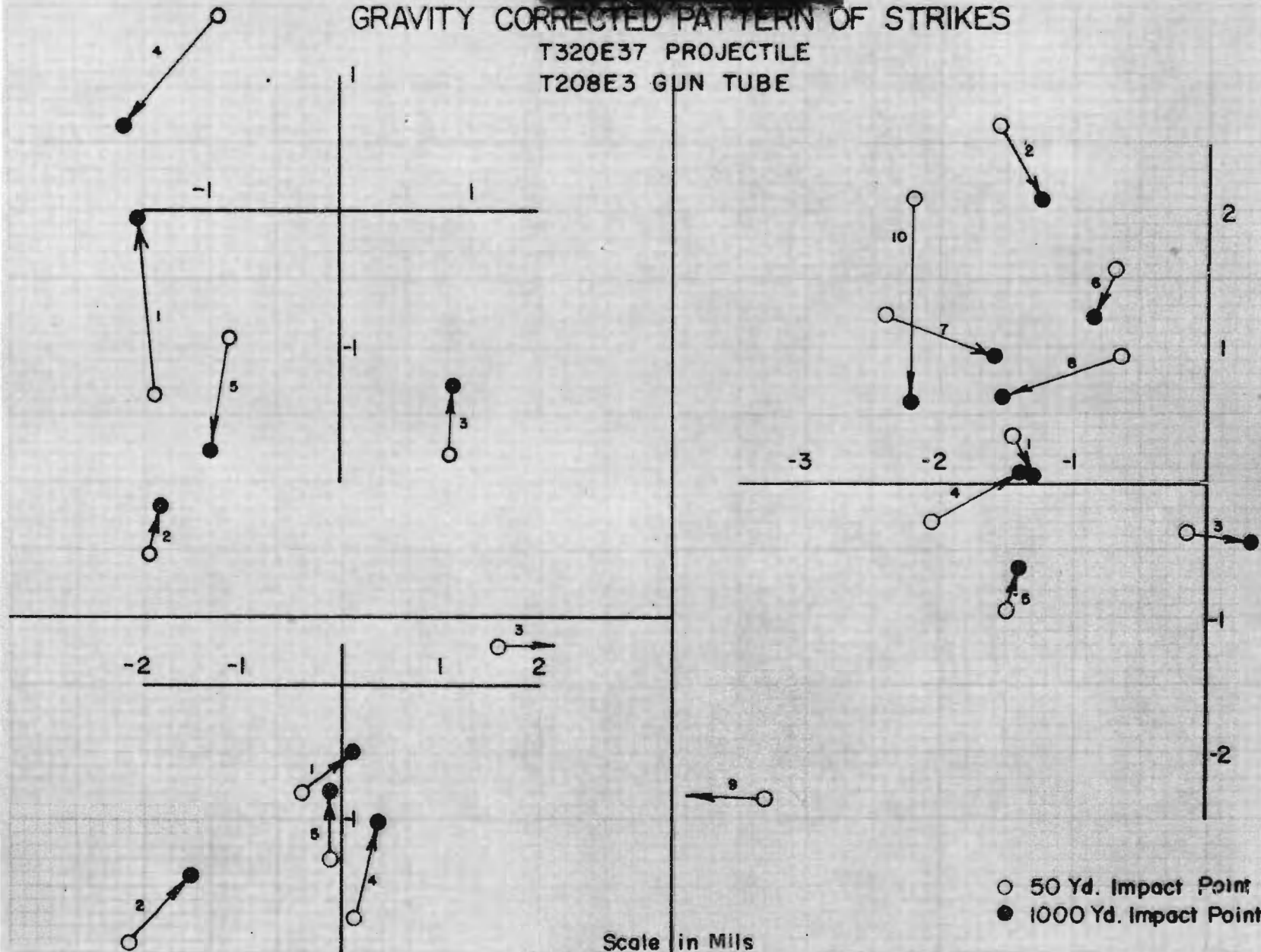
RD. 3876

FIG. 15

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GRAVITY CORRECTED PATTERN OF STRIKES T320E37 PROJECTILE T208E3 GUN TUBE



RD. NO. 3 MISSED 1000 YD. TARGET

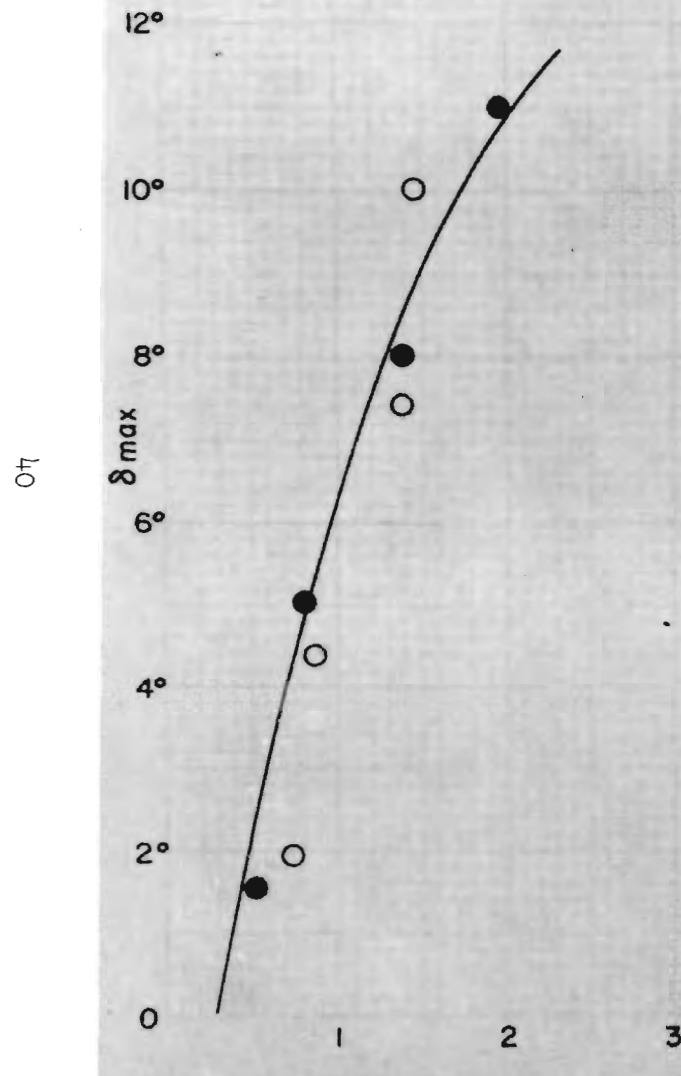
RD. NO. 9 MISSED 1000 YD. TARGET

FIG. 16

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DEVIATION FROM CENTER OF IMPACT VS FIRST MAXIMUM YAW



NO. RDS.

YAW GROUP

19

0° to 3° First Max.

20

4° to 6° " "

16

7° to 9° " "

9

10° to 12° " "

D&PS FIRINGS

IMPACT at 50 yds.

MILS

FIG. 17

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